

NLC - The Next Linear Collider Project



# **New NLC Final Focus**

**Pantaleo Raimondi and Andrei Seryi**

**SLAC**

**October 24-28, 2000**

**Linear Collider Workshop - LCWS 2000**



# Plan of the talk

- **Final Focus history**
- **Basic concepts of a “traditional” Final Focus**
- **Problems of a “traditional” approach**
- **Concepts of a new Final Focus**
- **Comparison of traditional and new FF**
- **Scaling to multi TeV region for the new FF**
- **Linear Collider Test Facility**
- **Conclusions**



## Final Focus task

### FF should focus the beams to small sizes at IP

- Chromaticity of FF is determined by the final doublet.
- FD chromaticity scales as  $L^*/\beta^*$ , and thus the chromatic dilution of the beam size  $\Delta\sigma/\sigma \sim \sigma_E L^*/\beta^*$  is very large.
- Design of a FF is driven by the necessity of compensating the FD chromaticity.



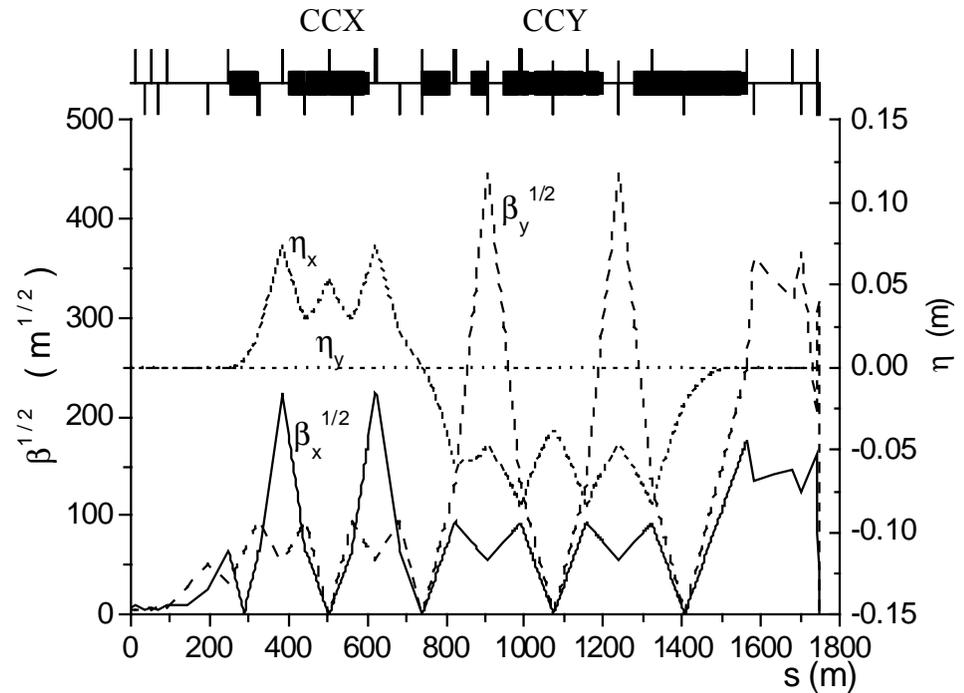
# Concepts of a “traditional” Final Focus

- Chromaticity is compensated in dedicated sections.
- Geometrical aberrations are canceled by using sextupoles in pairs with  $M = -I$ .

**FFTB and extrapolated NLC-FF design conceptually identical but...**

**FFTB ~150m long!**

**NLCFF ~1750m long!**



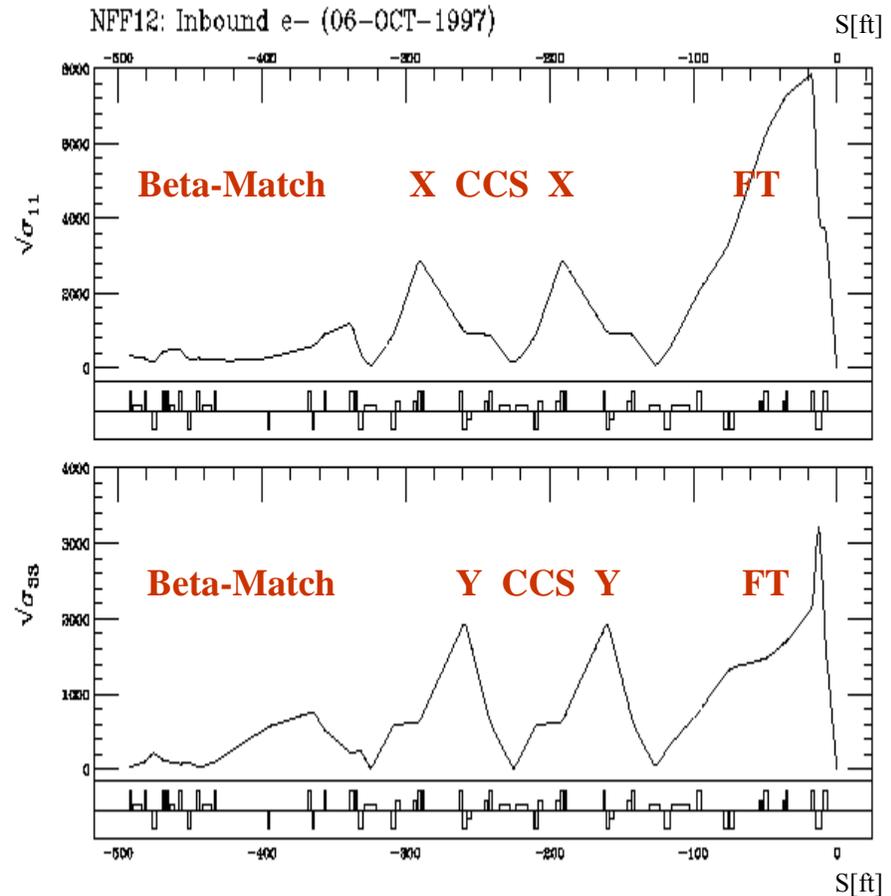
Optics of the traditional NLC FF.  
 $L^* = 2\text{m}$ ,  $\beta_x^* = 10\text{mm}$  and  $\beta_y^* = 0.12\text{mm}$ .

# SLC Final Focus

- **SLC Final Focus had X & Y Interleaved Chromatic Correction Sections, to save in total length**
- **Bends Short to save in total length**
- **Background issues hardly considered**

**Resulting aberrations small for the design beam parameters, but the limiting factors for the achieved ones:**

- **Less Current**
- **Smaller Emittances**



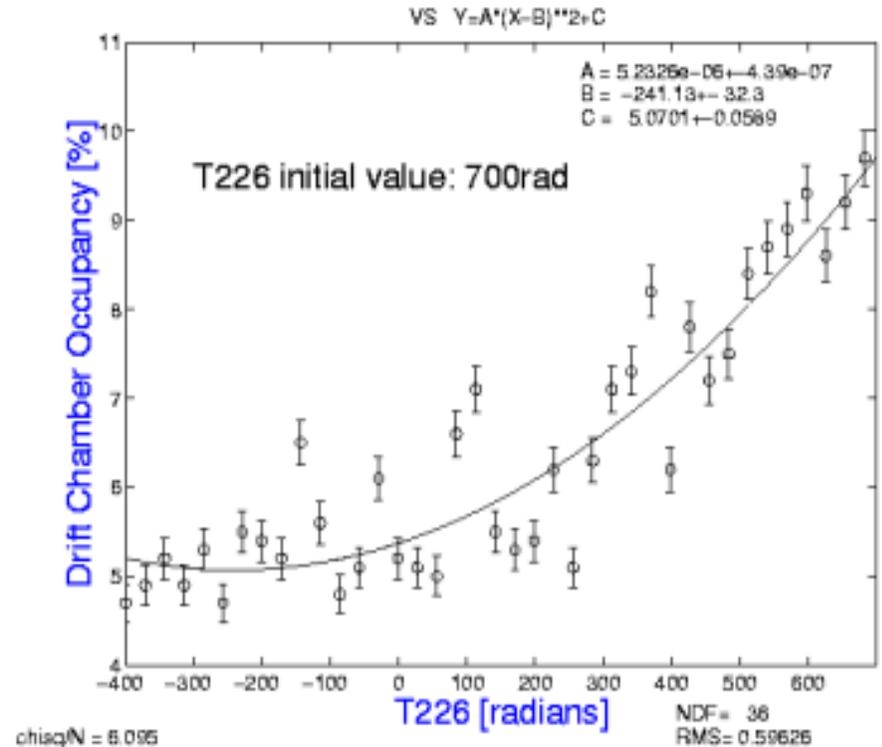
# SLC Background

Extensive tracking identified large contribution to the background from high order aberrations in the “FD phase” generated in the CCS.

As an example of the better understanding, sextupoles were added to minimize

$$T_{226} = \frac{d^2x'}{dx'dE/E}$$

Luminosity greatly improved, since smaller IP  $\beta$ 's were allowed and detector Up-Time increased



# SLC-FF and SLC-FF achievements

## SLC Final Focus

Beam Parameters	Design	Achieved
$\gamma\epsilon_x$	4.2e-5m·rad	5.5e-5m·rad
$\gamma\epsilon_y$	4.2e-5m·rad	1.0e-5m·rad
$\sigma_x$	1.65 $\mu\text{m}$	1.40 $\mu\text{m}$
$\sigma_y$	1.65 $\mu\text{m}$	0.70 $\mu\text{m}$

X & Y spot sizes limited by background and aberrations

**\* Most of the issues on tuning and understanding the FFS's optic solved through the years of SLC and FFTB operations**

## FFTB Final Focus

Beam Parameters	Design	Achieved
$\gamma\epsilon_x$	3.0e-5m·rad	2.8e-5m·rad
$\gamma\epsilon_y$	0.3e-5m·rad	0.1e-5m·rad
$\sigma_x$	1.00 $\mu\text{m}$	1.50 $\mu\text{m}$
$\sigma_y$	0.060 $\mu\text{m}$	0.060 $\mu\text{m}$

Jitter and background were some of the FFTB limitation



## Problems of traditional FF

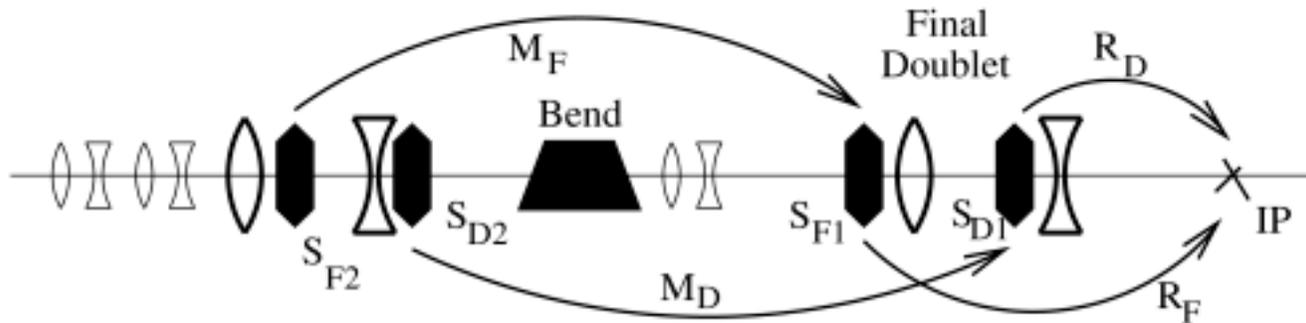
- **Chromaticity is not locally compensated**
- **Bandwidth is limited since  $M \neq -I$  for off energy particles.**
- **High sensitivity to  $\delta E$  in between the sources of chromaticity (due to wake-fields, synch.radiation).**
- **Bends have to be long and weak.**
- **Off-energy particles at IP and FD phases mix.**
- **Collimation in both FD and IP phases is necessary.**
- **System very long and scaling to higher energies is difficult.**



## **“Ideal” FF requirements**

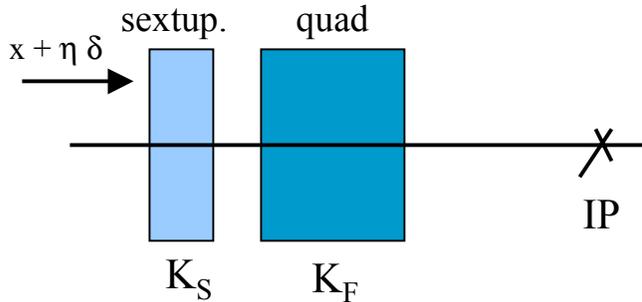
- **Chromaticity corrected locally.**
- **Number of bends minimized.**
- **Dynamic aperture (preservation of the linear optics) as large as possible.**
- **System as simple as possible.**
- **System optimized for flat beams.**

# Principles of the “ideal” FF



- **A Final Doublet is required to provide the necessary demagnification.**
- **The chromaticity is cancelled locally by two sextupoles interleaved with the FD together with a bend upstream to generate dispersion across them.**
- **Geometric aberrations of the FD sextupoles are cancelled by two more sextupoles placed in phase with them and upstream of the bend.**
- **Four more quadrupoles are needed for  $\beta$ -matching**

# Chromatic correction in FD



- Straightforward in Y plane
- a bit tricky in X plane:

Quad:  $\Delta x' = \frac{K_F}{(1+\delta)}(x + \eta\delta) \quad K_F(-\delta x - \eta\delta^2)$

Sextupole:  $\Delta x' = \frac{K_S}{2}(x + \eta\delta)^2 \quad K_S\eta\left(\delta x + \frac{\eta\delta^2}{2}\right)$

$\Delta x' = \frac{K_F}{(1+\delta)}(x + \eta\delta) + \frac{K_{\beta\text{-match}}}{(1+\delta)}x \quad 2K_F\left(-\delta x - \frac{\eta\delta^2}{2}\right)$

$K_{\beta\text{-match}} = K_F \quad K_S = \frac{2K_F}{\eta}$

chromaticity

Second order dispersion

If we require  $K_S\eta = K_F$  to cancel FD chromaticity, then half of the **second order dispersion** remains.

**Solution:**

The  $\beta$ -matching section produces as much X chromaticity as the FD, so the X sextupoles run twice stronger and cancel the **second order dispersion** as well.



## Second and higher order aberrations

- Second order aberrations produced by sextupoles are cancelled if

$$M_F = \begin{vmatrix} F & 0 & 0 & 0 \\ F_{21} & 1/F & 0 & 0 \\ 0 & 0 & F & 0 \\ 0 & 0 & F_{43} & 1/F \end{vmatrix}; \quad M_D = \begin{vmatrix} D & 0 & 0 & 0 \\ D_{21} & 1/D & 0 & 0 \\ 0 & 0 & D & 0 \\ 0 & 0 & D_{43} & 1/D \end{vmatrix}$$

where all nonzero parameters are arbitrary

**This requirements is less stringent than  $M=-I$ , so additional degrees of freedom available for fine tuning of higher order aberrations.**

- Higher order aberrations can be made to vanish for our beam parameters.



## Third order aberrations

- Third order geometric aberrations generated by sextupoles:

$$U_{1222} = K_{SD}K_{SF}R_{D12}^2R_{F12}^2\psi_{12}$$

$$U_{3444} = K_{SD}K_{SF}R_{D34}^2R_{F34}^2\psi_{12}$$

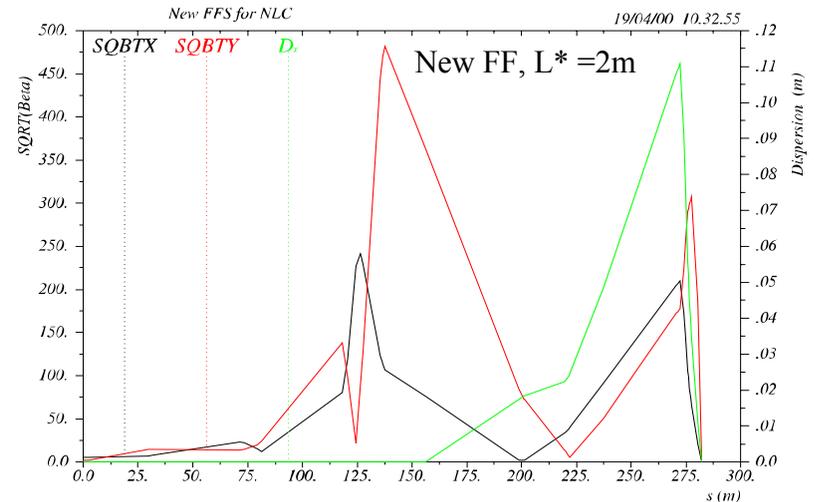
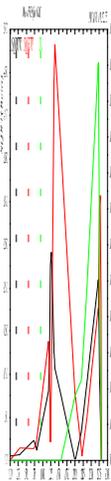
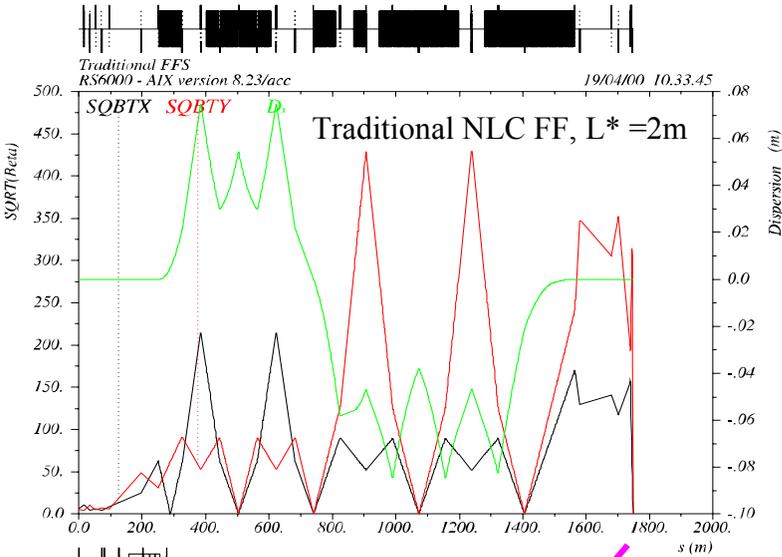
$$U_{1244} = U_{3224} = -\frac{1}{2}K_{SD}K_{SF}[\psi_{12}R_{D34}^2R_{F12}^2 \\ + \psi_{12}R_{D12}^2R_{F34}^2 - 4\psi_{34}R_{D12}R_{D34}R_{F12}R_{F34}]$$

where  $\psi_{12}$  and  $\psi_{34}$  are elements of transfer matrix between  $S_{F1}$  and  $S_{D1}$

- $U_{1222}$  and  $U_{3444}$  typically negligible
- $U_{1244}$  and  $U_{3224}$  can be made to vanish

# Traditional and new FF

A new FF with the same performance as NLC FF can be ~300m long, i.e. 6 times shorter





## Extension of the “minimal optics” concept

- **New FF has potentially much better performance than the traditional FF**
- **To use these capabilities and improve the system even further we incorporate:**
- **Twice  $L^*$** 
  - allows the use of large bore superconducting quadrupoles
  - simplifies the design of the detector
- **One additional weak bend at the entrance enlarges bandwidth**
- **One additional X-sextupole reduces horizontal aberrations**
- **A decapole close to the first sextupole reduces 4th order chromatic aberrations**
- **Soft bend downstream of the main bend reduces background**

# Optics of the new FF

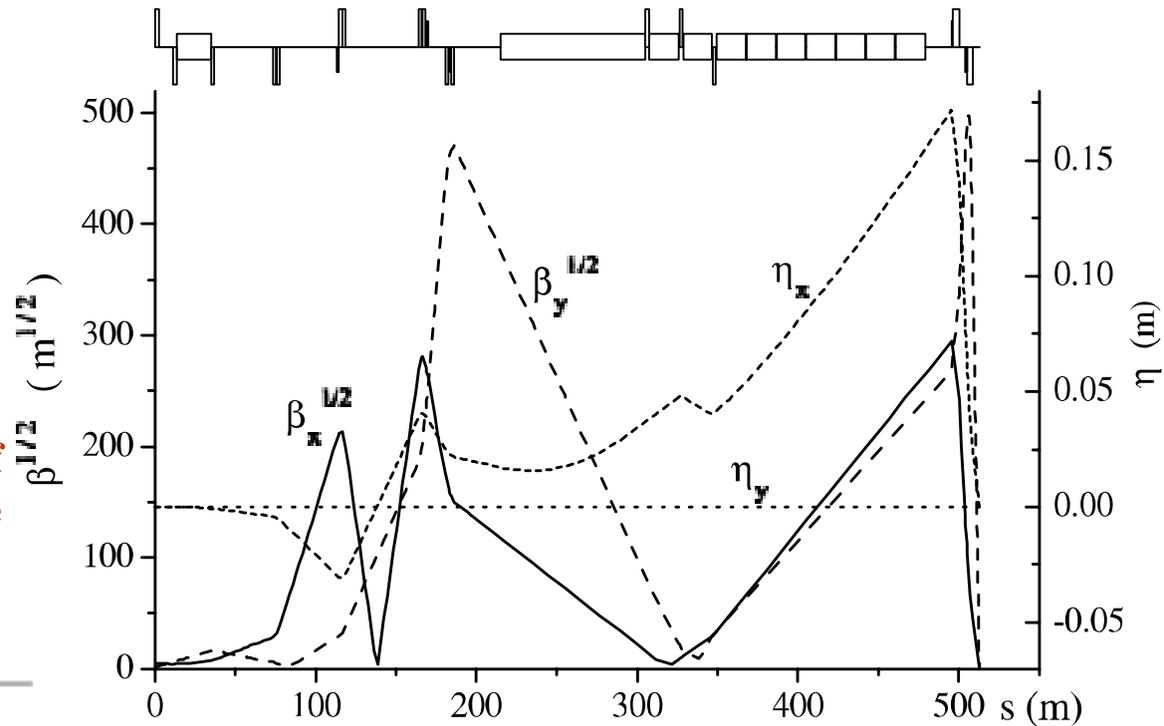
**New FF with twice  $L^*$  and with an additional bend and with soft bend.**

**Larger  $L^*$  allows the use of large bore quadrupoles which decreases collimation requirements.**

**Larger  $L^*$  also simplifies the design of the detector, and allows to make more rigid support of the FD.**

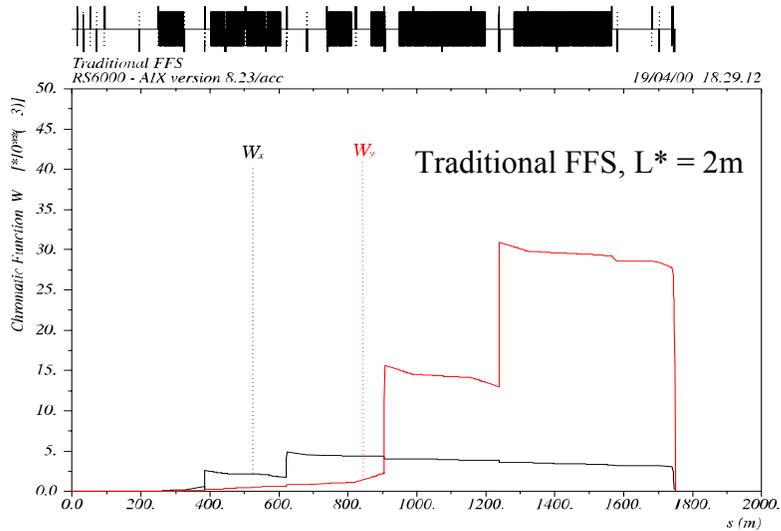
Table 1: Beam parameters

Beam energy (GeV)	500
Normalized emittances $\gamma\epsilon_x / \gamma\epsilon_y$ ( $\mu\text{m}$ )	4 / 0.06
Beta-functions $\beta_x / \beta_y$ at IP (mm)	9.5 / 0.12
Beam sizes $\sigma_x / \sigma_y$ at IP (nm)	197 / 2.7
Beam divergence $\theta_x / \theta_y$ at IP ( $\mu\text{rad}$ )	21/23
Energy spread $\sigma_E$ ( $10^{-3}$ )	3
Angular dispersion $\eta'_x$ at IP ( $10^{-3}$ )	5.4



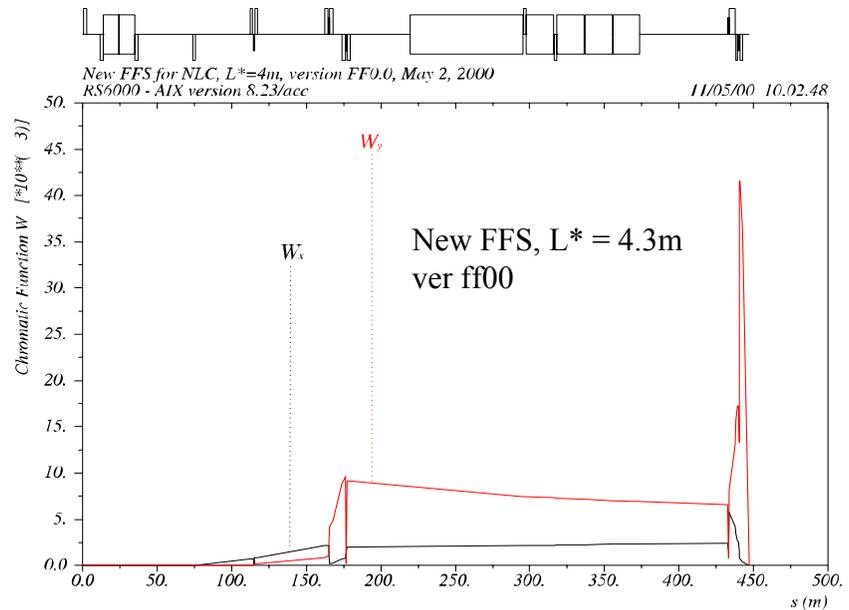
**Optics of the new NLC FF. (ver ff01)  
 $L^* = 4.3\text{m}.$**

# Chromaticity in traditional and new FF

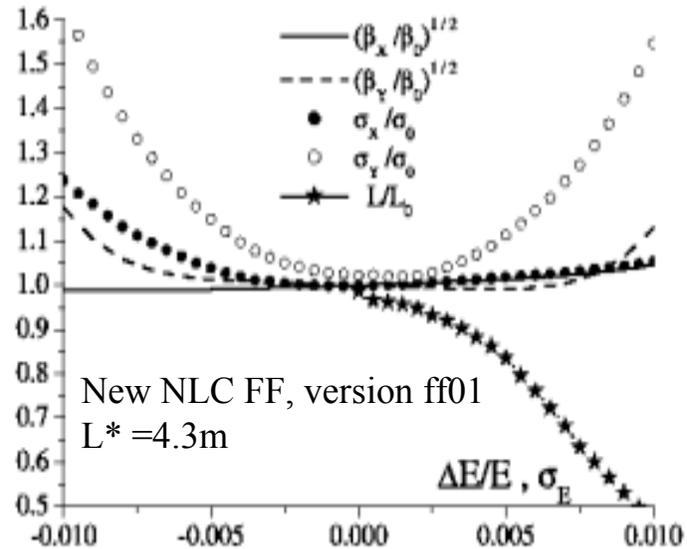
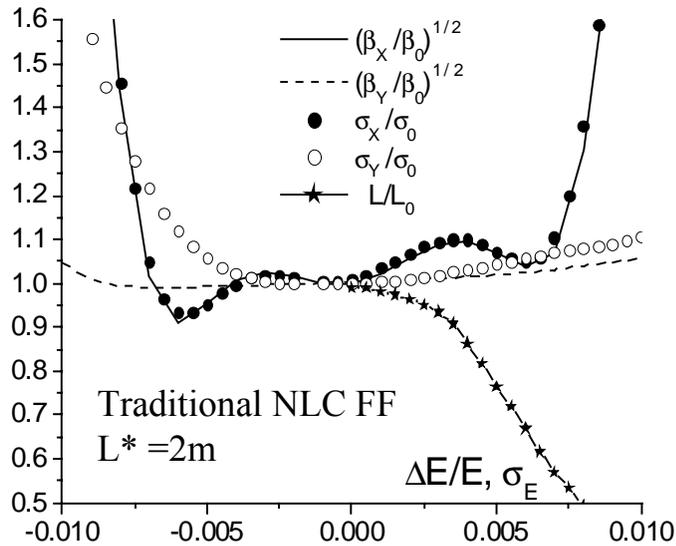


Large chromaticity through the FF results in high sensitivity to  $\delta E$  along the way for the traditional system

Chromaticity is much smaller through the new FF.



# IP bandwidth



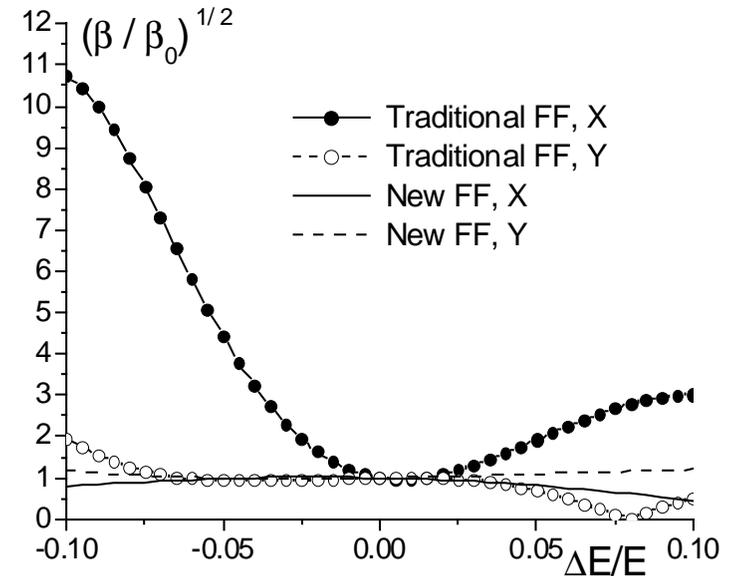
## IP bandwidth of the traditional and new NLC FF.

- $(\beta/\beta_0)^{1/2}$  -- the beam size defined from beta function vs  $\Delta E/E$
- $\sigma/\sigma_0$  -- luminosity equivalent beam size vs  $\Delta E/E$
- $L/L_0$  -- luminosity versus rms  $\sigma_E$

- **The IP bandwidth is very similar for these systems.**

# FD bandwidth

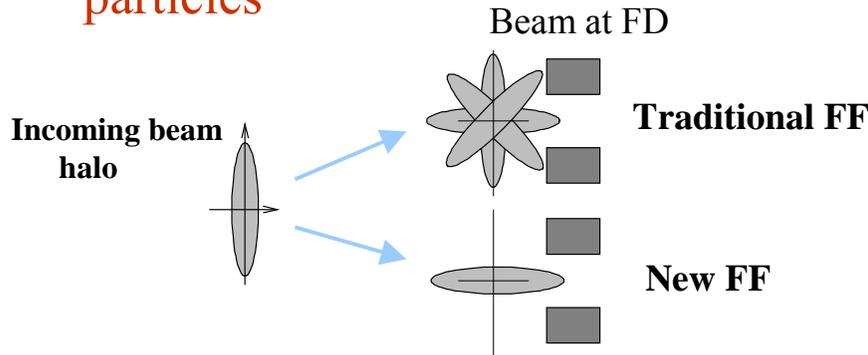
- **The FD bandwidth is rarely discussed but very important**
- **Large FD bandwidth is necessary to minimize background due to off energy particles**
- **New FF has much larger FD bandwidth**



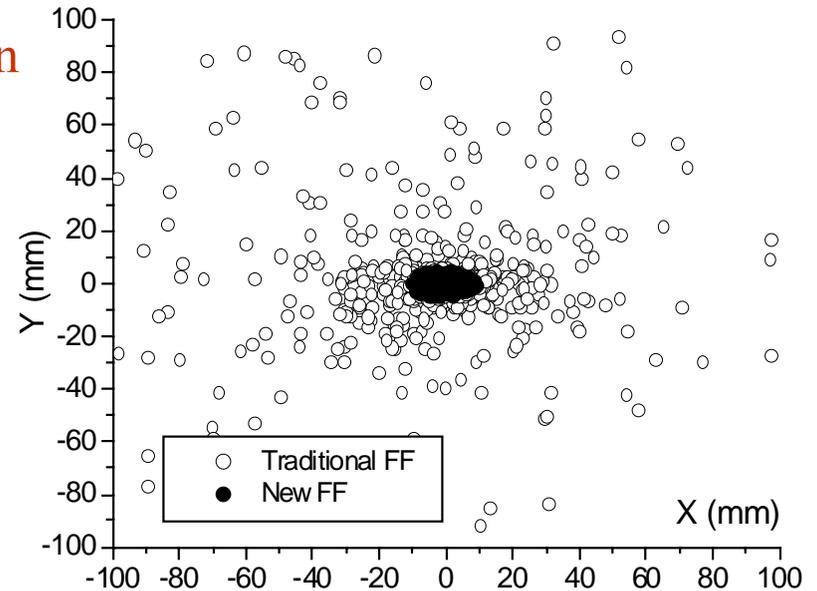
FD bandwidth of the Traditional and New NLC FF. Normalized betatron functions at the final doublet versus energy offset  $\Delta E/E$ .

# Collimation and background

- Traditional FF **does not preserve** betatron phase of halo particles
- New FF **does not mix** IP and FD phase particles



- ⇒ **Both IP and FD phase collimation required** for traditional FF
- ⇒ **Collimation design may benefit** from the phase conservation feature of the **new FF**



**Halo beam at the FD entrance.**  
**Incoming beam has 100 times larger coordinates in IP phase than in FD phase.**

Particles of incoming beam are placed on a surface of an ellipsoid with dimensions  $N_{\sigma}(x,x',y,y',E) = (800,8,4000,40,20)$  times larger than nominal beam parameters.



# Tuning and tolerances

- **Tuning is very similar for the new and traditional FF**
  - by moving sextupoles the IP dispersion, waist, coupling can be adjusted
- **Jitter positions tolerances are very similar**
  - *Global measure of the FF tolerances:*  
rms beam offset at the IP comes from vibration of optical elements produced by fast ground motion
- **Drift positions tolerances are somewhat tighter**
  - *increase of  $L^*$  is not absolutely free*



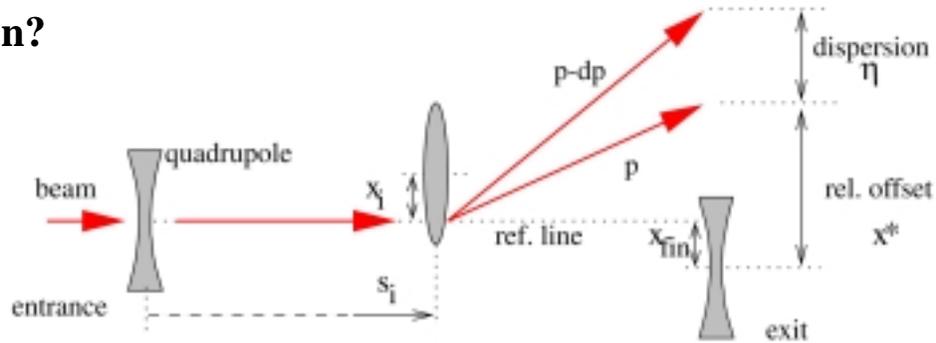


# How ground motion influence on the beam

## How to find trajectory offset or chromatic dilution?

Relative beam offset at exit and dispersion:

$$x^*(t) = \sum_{i=1}^N c_i x_i(t) - x_{fin} \quad \eta(t) = \sum_{i=1}^N d_i x_i(t)$$



Linear model:  $c_i = \frac{dx^*}{dx_i} \approx -K_i r_{12}^i$        $d_i = \frac{d\eta}{dx_i} \approx K_i (r_{12}^i - t_{126}^i)$       Approximate values are for thin lens, linear order

Then, for example, the **rms beam dispersion**:

$$\langle \eta^2(t) \rangle = \int_{-\infty}^{\infty} P(t, k) G_\eta(k) \frac{dk}{2\pi} \quad \text{where} \quad P(t, k) = \int_{-\infty}^{\infty} P(\omega, k) 2[1 - \cos(\omega t)] \frac{d\omega}{2\pi}$$

and  $G_\eta(k) = \left( \sum_{i=1}^N d_i (\cos(ks_i) - 1) \right)^2 + \left( \sum_{i=1}^N d_i \sin(ks_i) \right)^2$       - **spectral response function**

Sum rules. E.g.  $d_i s_i = -T_{126}$  at small k then  $G_{offset}(k) \approx k^2 R_{12}^2$        $G_\eta(k) \approx k^2 T_{126}^2$       unless  $R_{12}$  or  $T_{126} = 0$



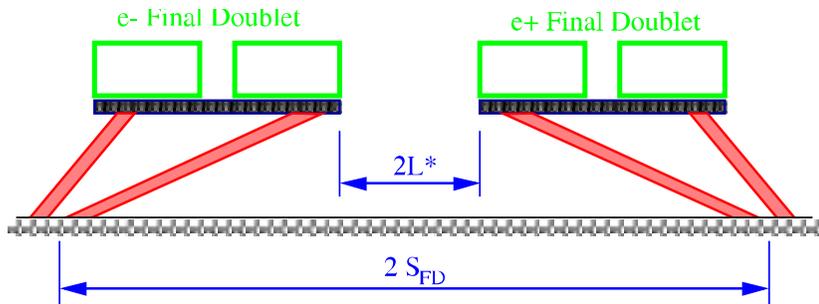
# Comparison in terms of fast ground motion

**Rms Y offset at IP is ~1.2nm for both new and traditional FF.** Assumptions:

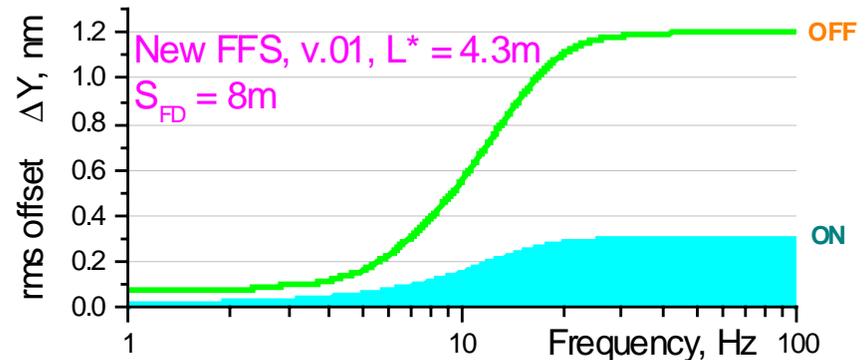
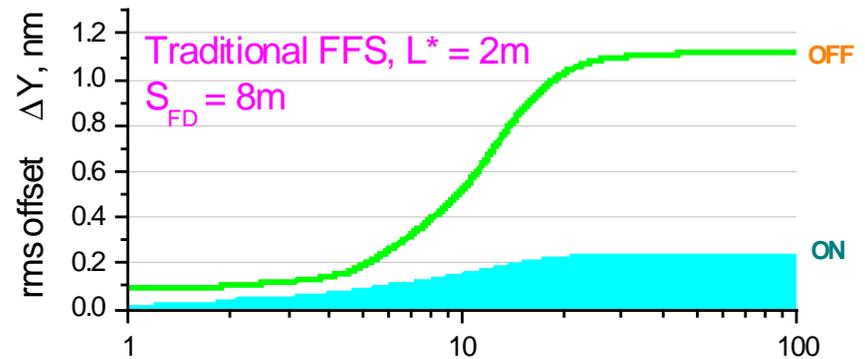
- “SLAC 2am” ground motion model;
- feedback with  $f_0=6\text{Hz}$ ;
- support of FD is 8m away from IP;
- FD does not tilt

**N.B.** FF with longer  $L^*$  may result in less  $\Delta Y$  since more rigid support for the FD is possible.

**If the FD contribution to  $\Delta Y$  vanishes (e.g. by an active system) then  $\Delta Y \sim 0.3\text{nm}$ .**

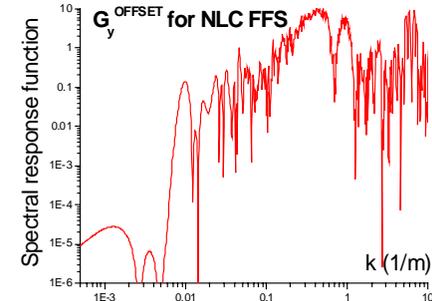
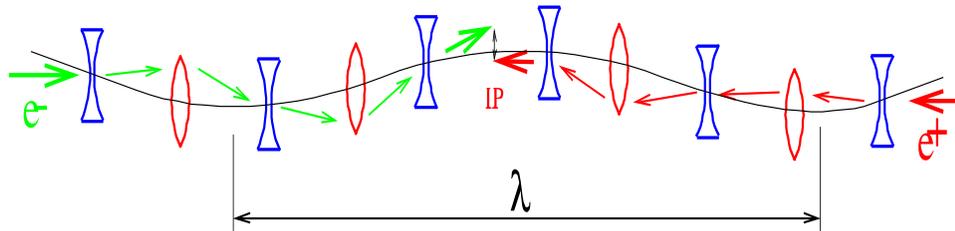
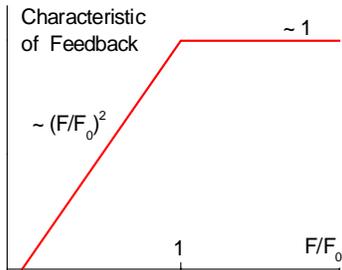


Vertical RMS offset of  $e^+ e^-$  beams at the IP  
 Ground motion "SLAC 2am"; feedback  $f_0=6\text{ Hz}$ ; ideal quad supports  
 Ideal FD stabilization ON/OFF



Ground motion frequencies giving most contribution to RMS offset

# Ground motion induced beam offset at IP



**rms beam offset at IP:**

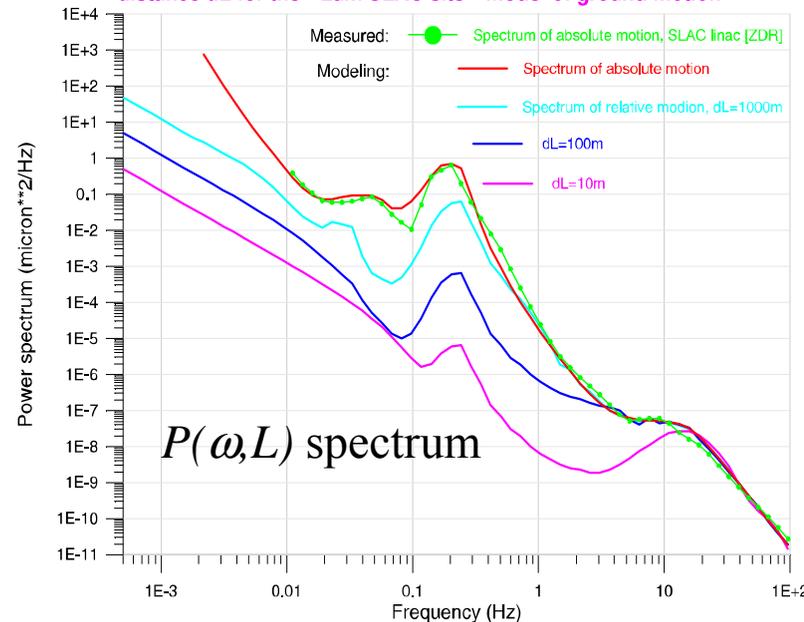
$$\propto P(\omega, k) \cdot G(k) \cdot F(\omega) \cdot dk \cdot d\omega$$

$G(k)$  - spectral response function

$F(\omega)$  - performance of inter-bunch feedback

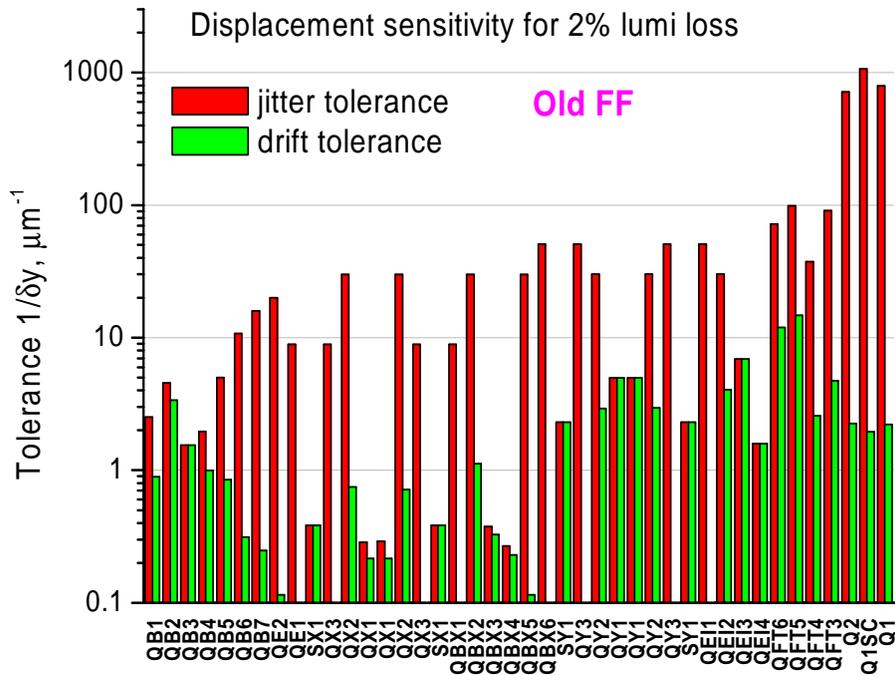
$P(\omega, k)$  - 2D spectrum of ground motion

Spectra of absolute and relative motion of two points separated by distance  $dL$  for the "2am SLAC site" model of ground motion.

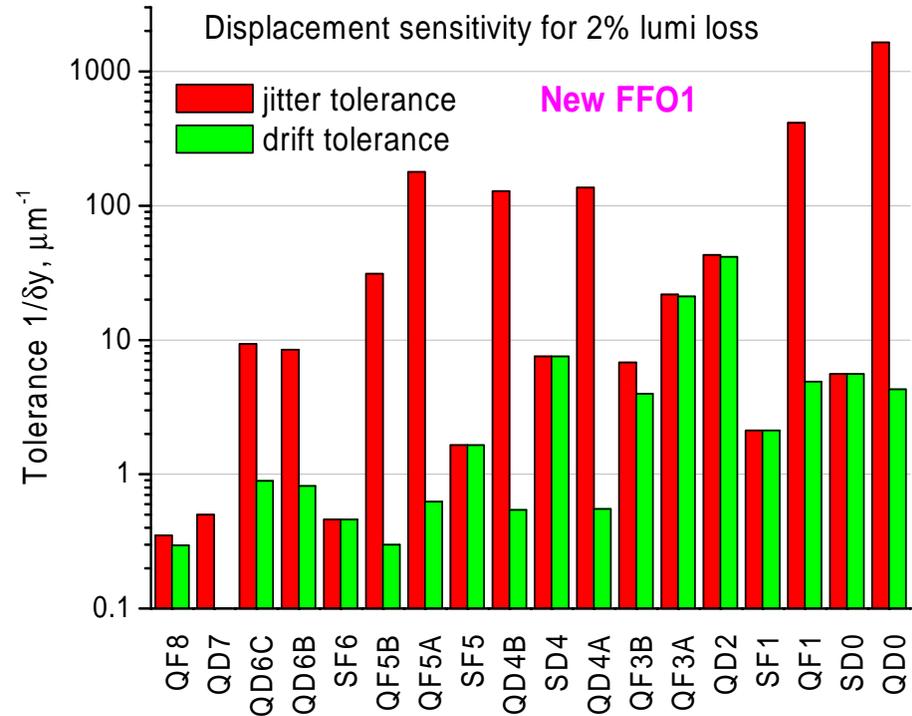


# Tolerance to vertical motion of magnets

## Old FF, $L^* = 2m$



## New FF, $L^* = 4.3m$



**Tolerance  $1/\delta y$  for 2% luminosity loss:**  
**jitter - no correction**  
**drift - IP offset and angle are corrected**

Calculated with FFADA

Beam energy, GeV	500
$\gamma \epsilon_x / \gamma \epsilon_y$ ( $10^{-8}$ m)	400 / 6
$\sigma_x^* / \sigma_y^*$ at IP (nm)	197 / 2.7
Energy spread $\sigma_E$ ( $10^{-3}$ )	3



# Scaling with emittance

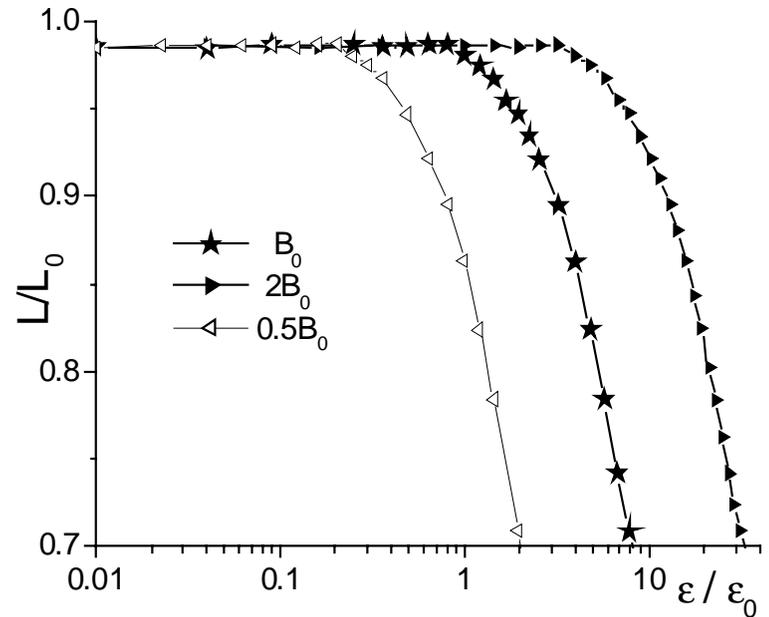
- Increasing  $\epsilon$  will increase contribution of aberrations to  $\sigma^*$
- If  $\epsilon$  changed *significantly*, then, to keep the contribution of aberrations constant, bend field should scale as

$$B_0 \sim \epsilon^{1/2}$$

- This scaling is natural since

$$\eta'/\theta^*$$

is then also constant



**Luminosity vs emittance** for the new FF for the nominal, twice larger and twice lower **field in the bends**.  
Tracking without synchrotron radiation.

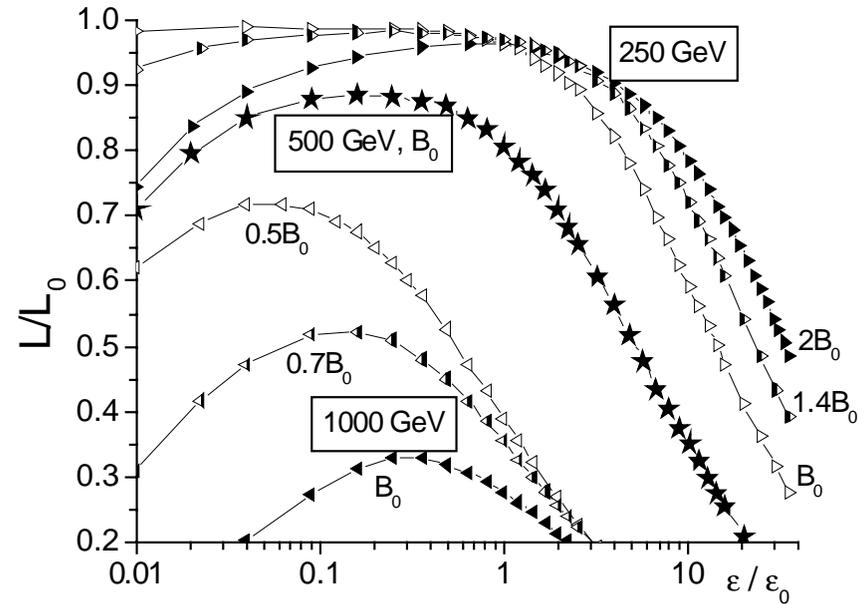


# Energy range

**A fixed length FF can operate in a wide range of energies.**

- **Scaling to lower energies is easy. Rescaling of bends may be required.**
- **SR contribution increase for high energies, but this growth is slowed by**

**$B_0 \sim \epsilon^{1/2} \sim 1/\gamma^{1/2}$  bend rescaling.**

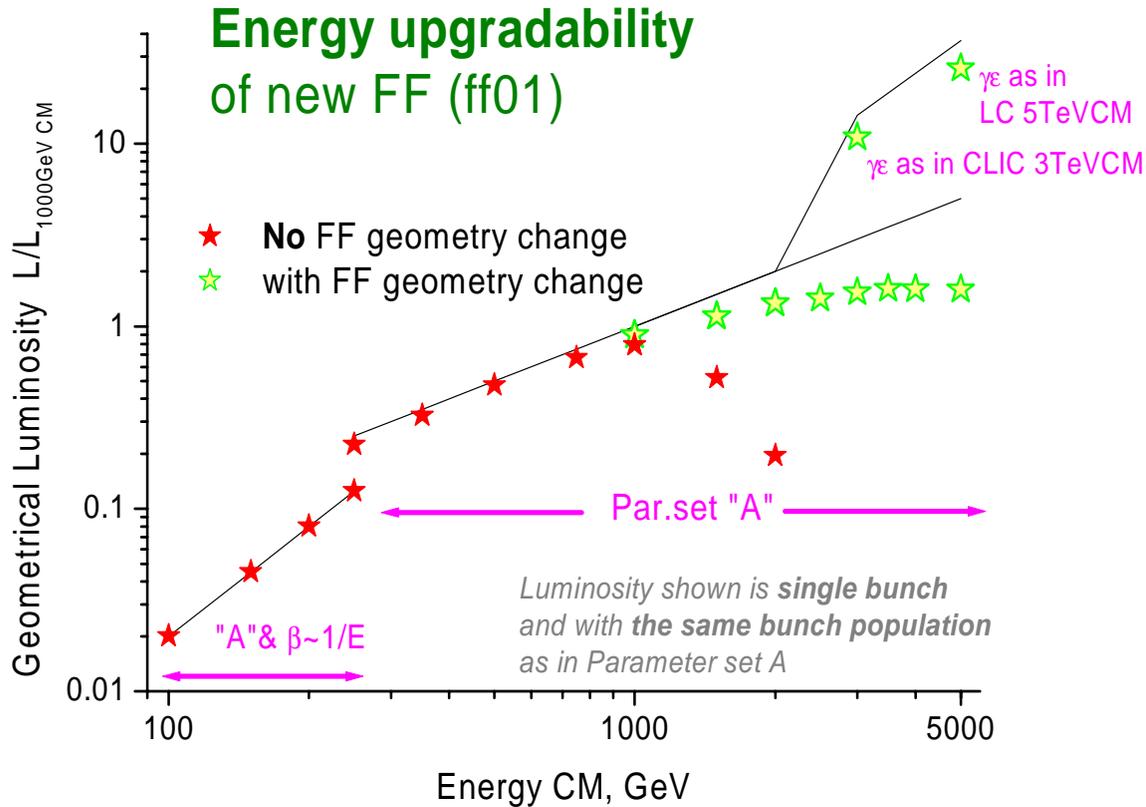


Luminosity vs emittance for different bend field and beam energy  
 New FF, ver.ff00.  
 Tracking with sync.rad.



# Scaling with emittance & energy

- **New FF does NOT require changing FF geometry up to ~ 1TeV CM**
- **From 1TeV and higher one need to adjust geometry**
- **For 1TeV => few TeV the IP either moves (~20cm) or kept fixed by adjusting upstream of FF optics**



**Geometrical Luminosity vs CM energy for the new FF for different parameter sets**



## Scaling with energy

- Length of traditional FF designed so far ~ linear with E

	FFTB	NLC traditional	CLIC
E , GeV	50	500	1500
L , m	150	1750	3100
$\gamma\epsilon_{x/y}$ , $\mu\text{m}$	30/3	4/0.07	0.7/0.02

- Note that  $\gamma\epsilon$  decrease roughly  $\sim 1/E$
- New FF is more suitable for scaling to higher energy

$$\text{New FF Length} \propto \gamma^{7/10} \text{ if } \gamma\epsilon = \text{const}$$

$$\text{or } \propto \gamma^{2/5} \text{ if } \gamma\epsilon \sim 1/E$$

- With the new FF scheme, a 3 TeV CM FF could be only about 600m.

# Scaling with energy, assumptions

- **IP beam size dilution dominated by SR in magnets:**

$$\frac{\Delta\sigma_y^2}{\sigma_y^2} \propto \frac{\gamma^5}{L^2} \eta_B'^3 \propto (\gamma\epsilon_y)^{3/2} L^{*3} \left( \frac{\eta_{IP}'^2}{\epsilon_x} \right)^{3/2} \left( \frac{\epsilon_x}{\epsilon_y} \right)^{3/2} \frac{\gamma^{7/2}}{L^5}$$

where  $\eta_B'$  angular dispersion produced by bends  $\eta_B' \propto \eta_{IP}' L^* / L$

IP dispersion  $\sim$  IP beam divergence

*Assume*

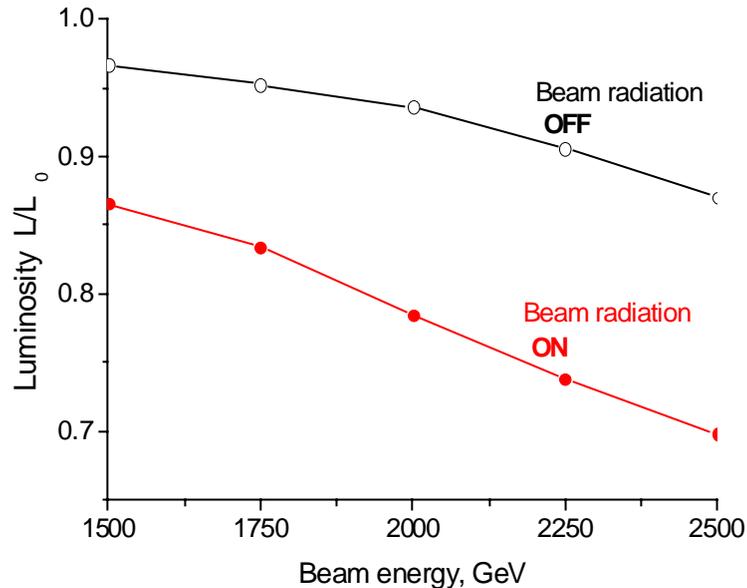
Constant IP beta, chromaticity,  $L^*$ , length FD

Imply that can achieve gradients required.  
Can deal with increased position stability tolerance

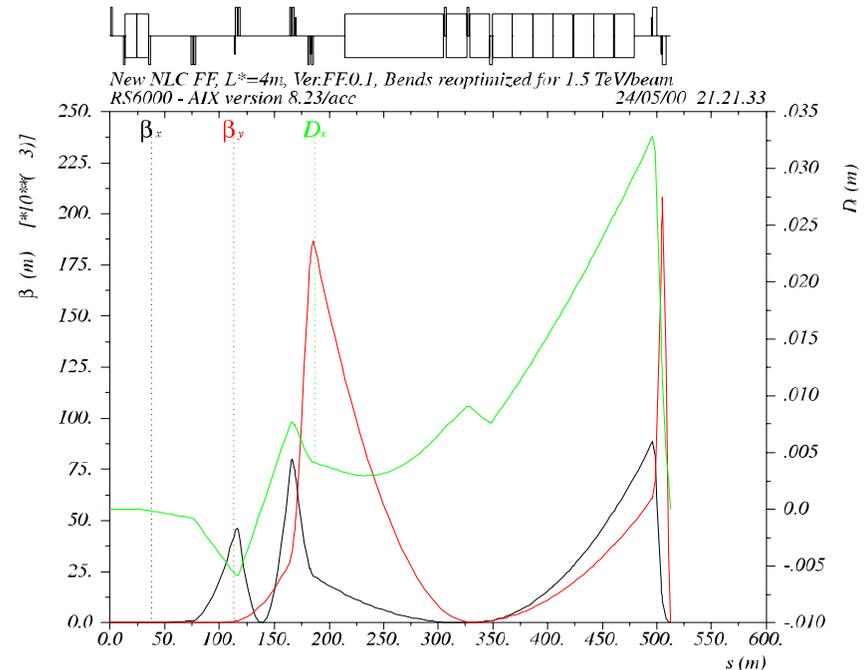
- **Then, if norm.emittance=const then  $L \propto \gamma^{7/10}$**
- **If norm.emittance  $\sim 1/E$  then  $L \propto \gamma^{2/5}$**

# 5 TeV/CM FF

**A FF for 3 - 5TeV CM collider can be just about 0.5-1 km long!**



**Luminosity  $L/L_0$  versus beam energy. Beta functions at IP fixed. Angular dispersion at IP reoptimized at each energy .**



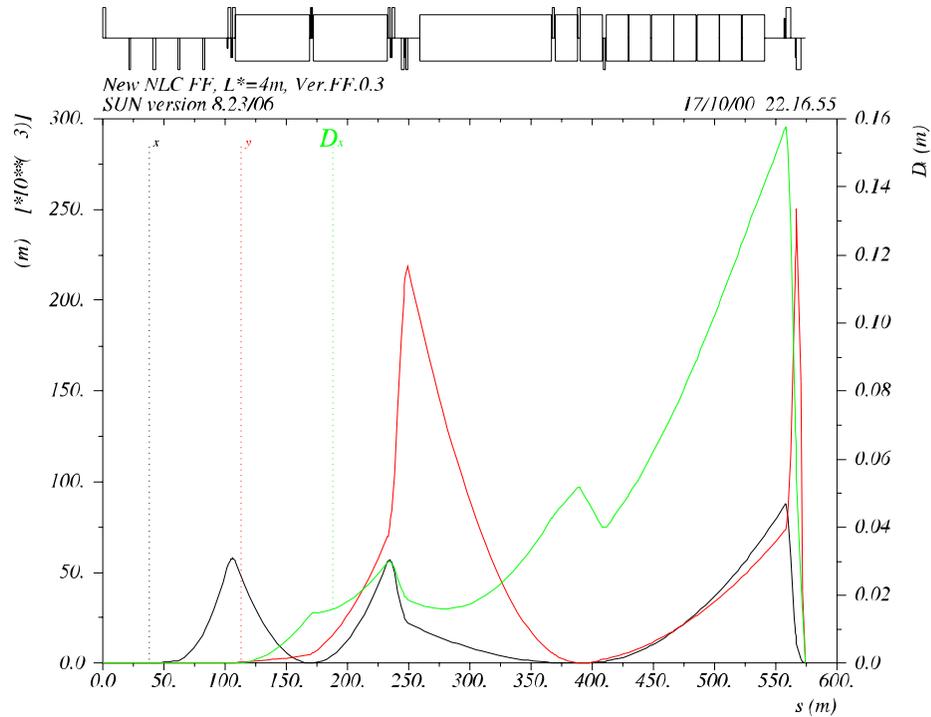
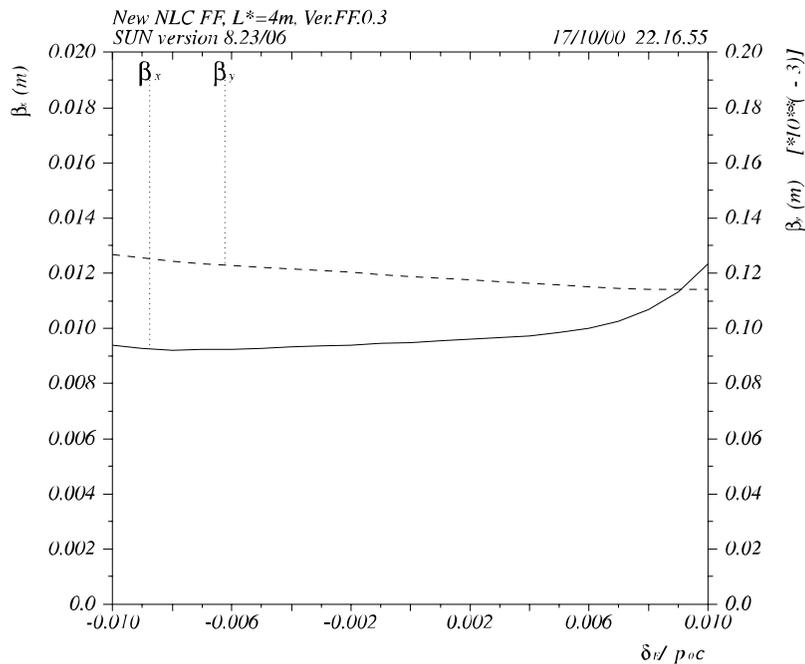
### BEAM PARAMETERS

$\gamma\epsilon_x / \gamma\epsilon_x$ at IP ( $10^{-8}$ m)	50 / 1
$\beta_x^* / \beta_y^*$ (mm)	9.5 / 0.14
$\sigma_x^* / \sigma_y^*$ at 2500GeV/beam (nm)	31 / 0.54
Energy spread $\sigma_E$ ( $10^{-3}$ )	2

J.P.Delahaye, G.Guignard, J.Irwin, T.O.Raubenheimer, R.D.Ruth, I.Wilson, P.B.Wilson, "A 30 GHz 5-TeV Linear Collider", PAC 1997.

# Latest developments of new FF

Inspired by LCTF FF, investigating possibility to create better knobs for high order dispersion...





## New FF benefits

- **New FF is much shorter, providing a significant cost reduction for the collider.**
- **New FF has similar bandwidth and several orders of magnitudes larger dynamic aperture than the traditional FF.**
- **Background is less of an issue in the new design. Thanks to the expected benefits the collimation section may be relaxed with the new FF.**
- **$L^* = 4.3\text{m}$  for the new FF simplifies engineering of the IP area, and probably helps the stabilization of the final doublet.**
- **Scaling to multi-TeV region is extremely attractive for the new FF.**
- **Further improvements of the system are under study...**

**(and seem possible)**



# LCTF hypothesis

**It is conceivable to utilize the existing hardware at SLAC to realize a “Linear Collider Test Facility”**

- **Test bench for various NLC applicable ideas and techniques**
- **Logical and useful addition to NLCTA, Orion, ATF...**
- **LCTF is an Interaction Region oriented test facility**
- **Keep LCTF running until NLC is commissioned to maintain “beam handling state of the art” and train new people**
- **LCTF can start with:**
  - **Test the New Final Focus scheme**
  - **Collide beams with NLC beta functions and bunch length, and ~ 70 nm vertical spot sizes**
  - **Develop and test IR vibration counteraction *in vivo***
  - **Feed forward jitter suppression**
  - **Nano-meter level beam stabilization at the IP**
  - ***...and much more***



# Basic Premises

- **e<sup>+</sup> and e<sup>-</sup> beams are almost always available at the end of the Linac @ 30Hz and  $N \sim 2.5e10$ , with good emittances**
- **LCTF operation should not be in conflict with PEP-II operation**
- **Refurbishing of Arcs and FF existing hardware reasonably affordable**
- **The FF modifications, which mainly require a new FD, *is affordable* even by SLAC alone, *but***
- **LCTF will attract other labs and a solid *international collaboration* between all the labs involved in linear collider R&D could be established, to share efforts and costs.**



# Upgrades list

- **Final Focus Upgrade**

The Final Focus should be modified according to the new Final Focus scheme. We expect to have very small residual spot size dilutions down to NLC-like IP beta functions.

- **Damping Rings Upgrade**

Rearrange the QFs and power feeds and add Booster Power Supplies. We expect to decrease both horizontal and equilibrium vertical emittances by about a factor 3:

$$\gamma\epsilon_x = 1e-5m*rad \quad \gamma\epsilon_y = 0.05e-5m*rad$$

## Desired

- **Rings to Linac Upgrade**

A more suitable bunch compressor with better compression and less emittance growth should be studied and implemented.



# LCTF parameters

- Based on conservative extension of the achieved SLC parameters
- Work at 30GeV @10Hz to reduce synch.rad in arcs, FF, and to reduce electricity bill (e.g. for arcs: ~ 1MW @45.6GeV per arc)
- Work with lower current to improve beam stability

**Emittances routinely achieved at SLC @45.6GeV and  $N^{\pm} = 1.5e10$  :**

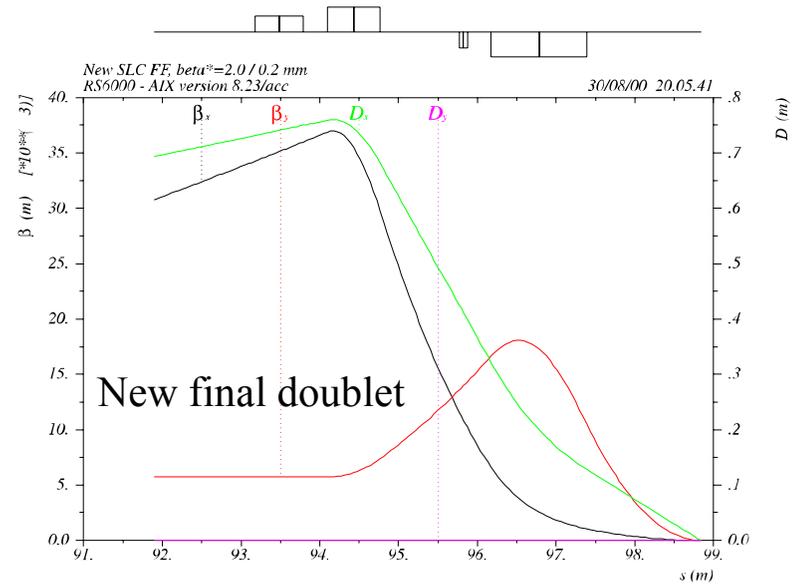
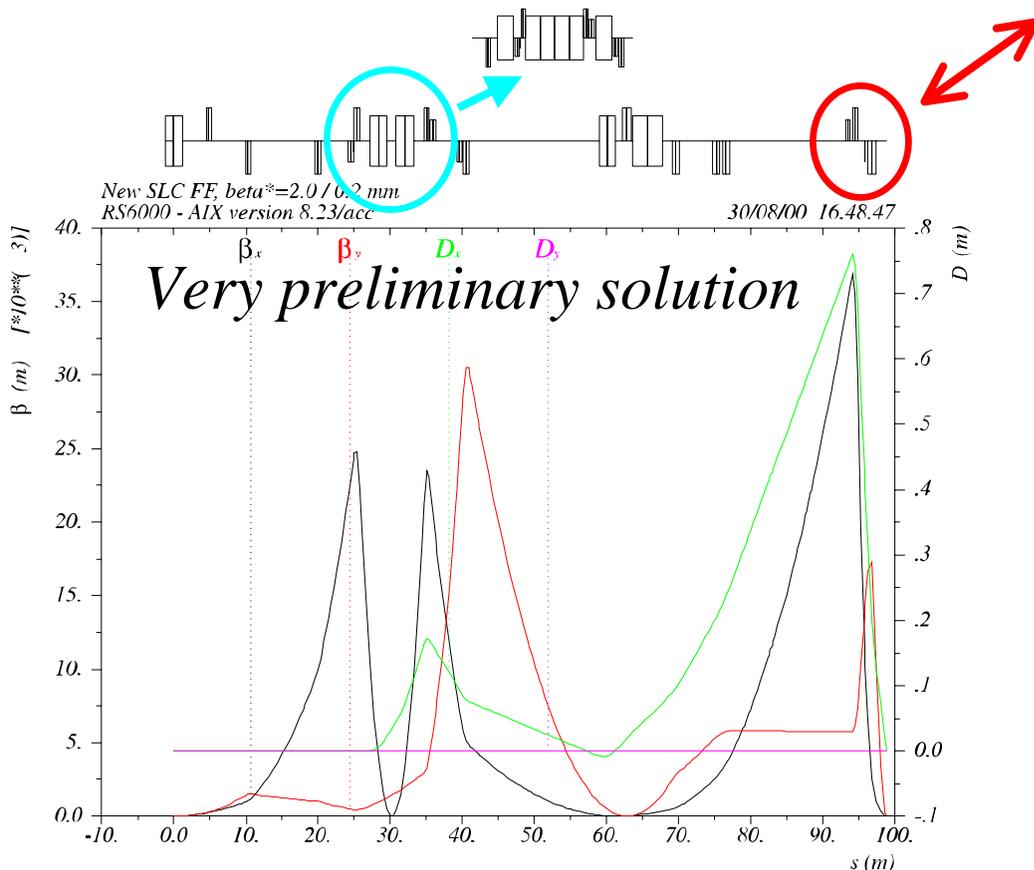
- Damping ring:  $\gamma\epsilon_{x,y} = 2.9/0.15E-5m$
- Final focus:  $\gamma\epsilon_{x,y} = 4.0/0.30E-5m$  (synch.rad. Arc contribution:  $\Delta\gamma\epsilon_{x,y} = 1.1/0.15E-5m$ )

## LCTF parameters

- **Beam Energy:** 30 GeV
- **DR emittances:**  $\gamma\epsilon_{x,y} = 1.0/0.05E-5m$
- **FF emittances:**  $\gamma\epsilon_{x,y} = 1.6/0.16E-5m$
- **IP Betas:**  $\beta_x = 2mm$   $\beta_y = 0.2mm$
- **Bunch length:**  $\sigma_z = 0.8 - 0.2mm$
- **IP spot sizes:**  $\sigma_{x,y} = 750/75nm$
- **Beam currents:**  $N^{\pm} = 1.0e10$

# LCTF Final Focus optics

- Use existing SLC FF
- Make MIN modifications



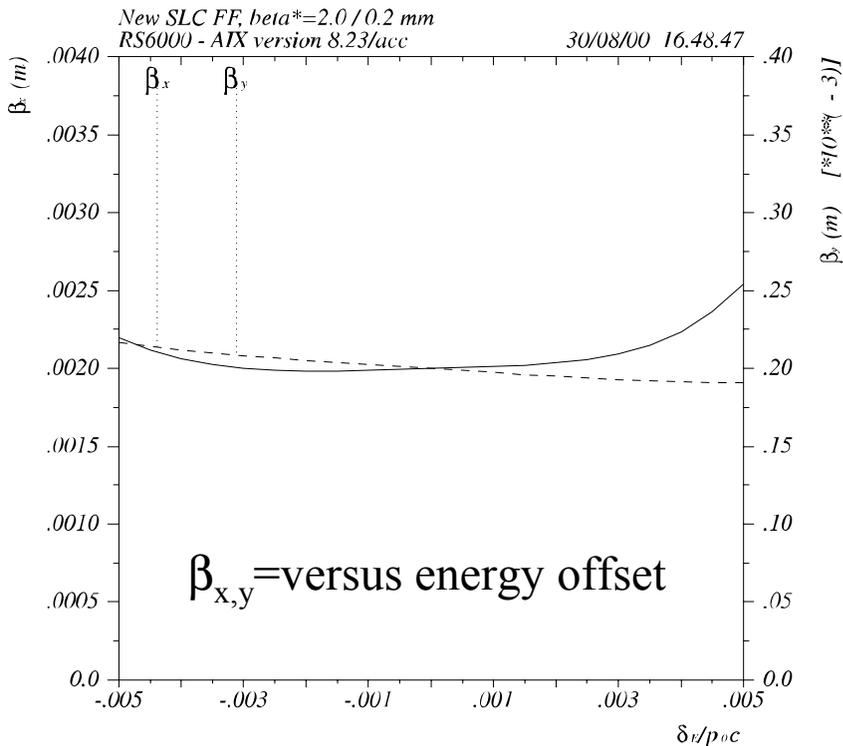
- Required modifications:
  - final doublet
  - make bend B2 longer (to reduce sync.rad. effect in horiz. beam size)

LCTF final focus with  $\beta_{x,y} = 2/0.2\text{mm}$ ,  $L^* = 1.5\text{m}$

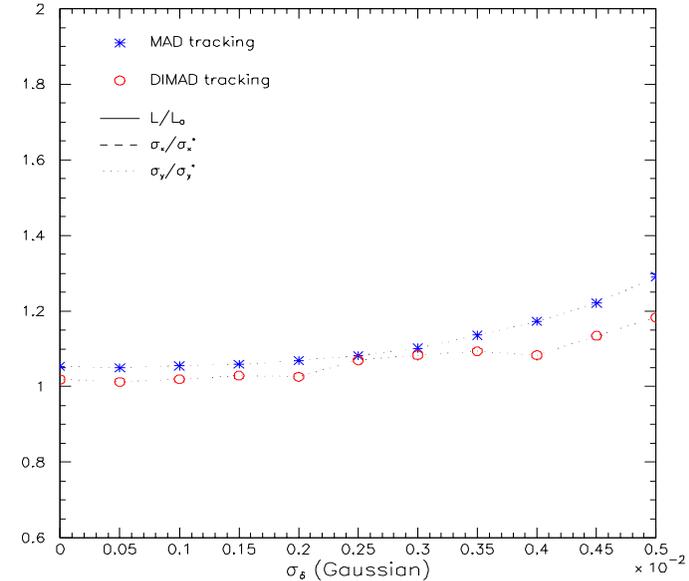


# LCTF Final Focus optics

- **Chromo-geometrical aberrations:**
  - **acceptable**



TRACKING RESULTS vs. ENERGY SPREAD



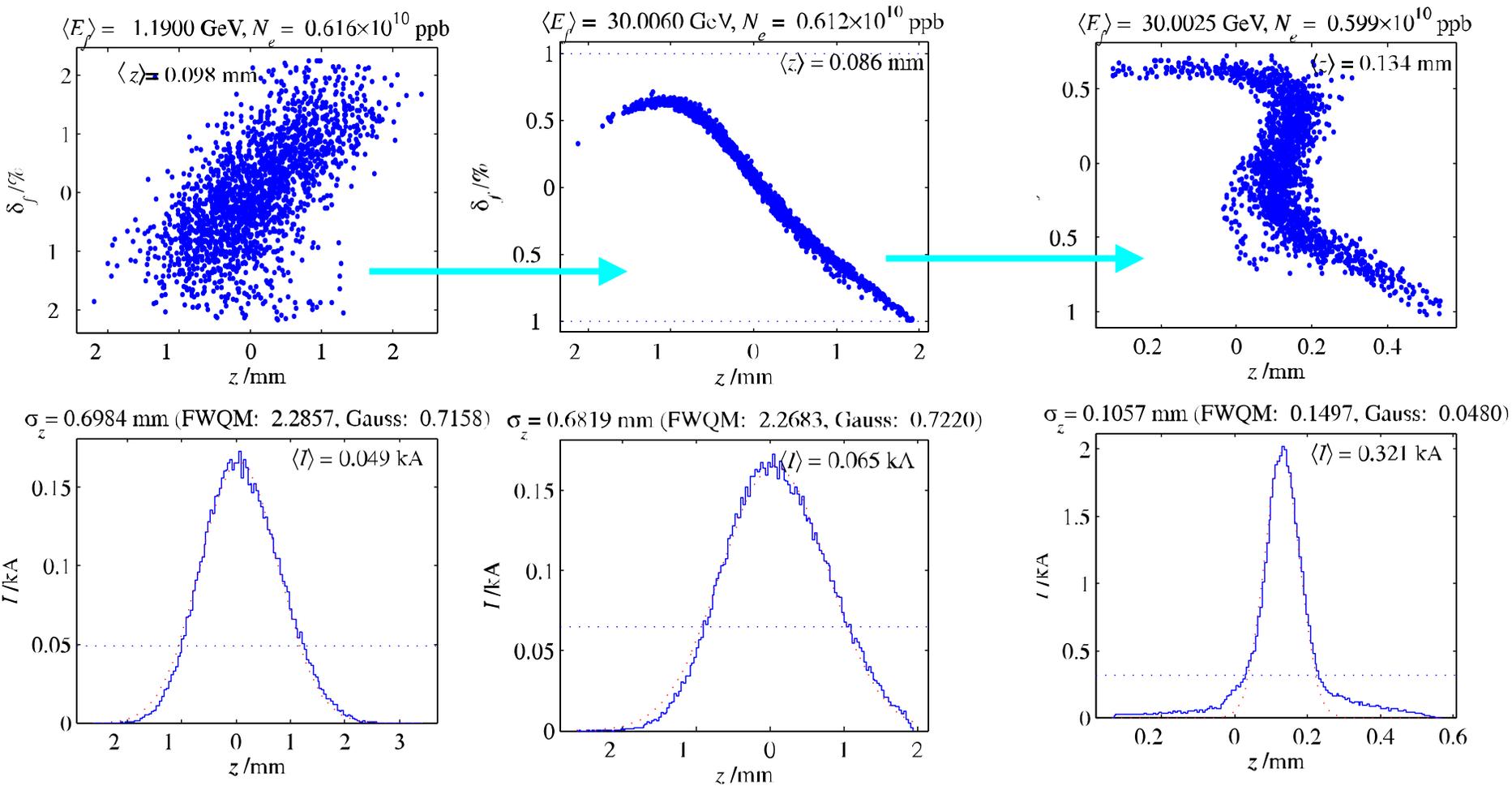
- **Tracking: OK in Y (~70nm)**
- **x1.6 in X due to sync.rad. in B2 at 30GeV (worse at 46GeV)**
  - **by making B2 longer this effect can be almost eliminated**
  - *further optimization of the optics is possible* P.Raimondi, A.Seryi



# Final doublet

- **Final doublet options:**
  - **superconductive: modify existing SC triplet, or build from scratch**
  - **electromagnets**
  - **permanent magnet quads**
- **The permanent magnet options is most reasonable, because**
  - **not as expensive as SC (FF Cryo plant gone...)**
  - **allows to test solutions relevant for NLC**
- **Variety of options of FD stabilization**
  - **active vibration suppression with reference to ground and inertial frame**
  - **feedforward correction of magnetic center position by dipole coils**
  - **etc.**

# Bunch compression in Arcs



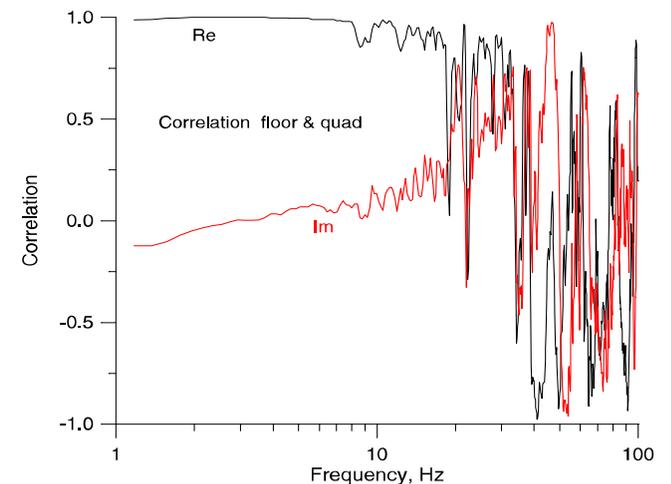
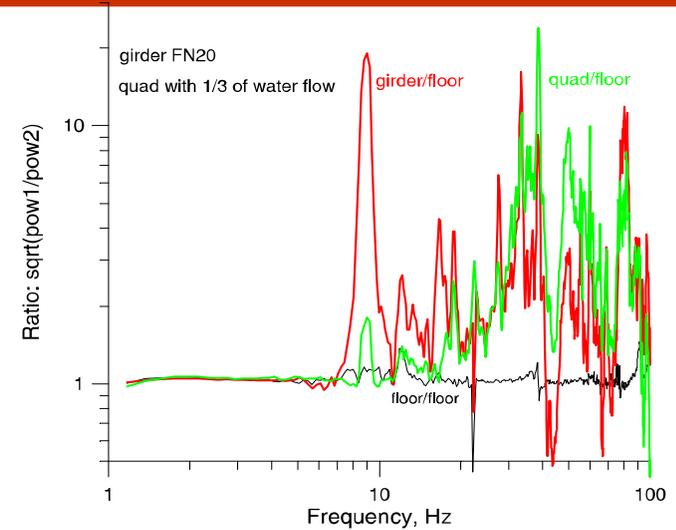
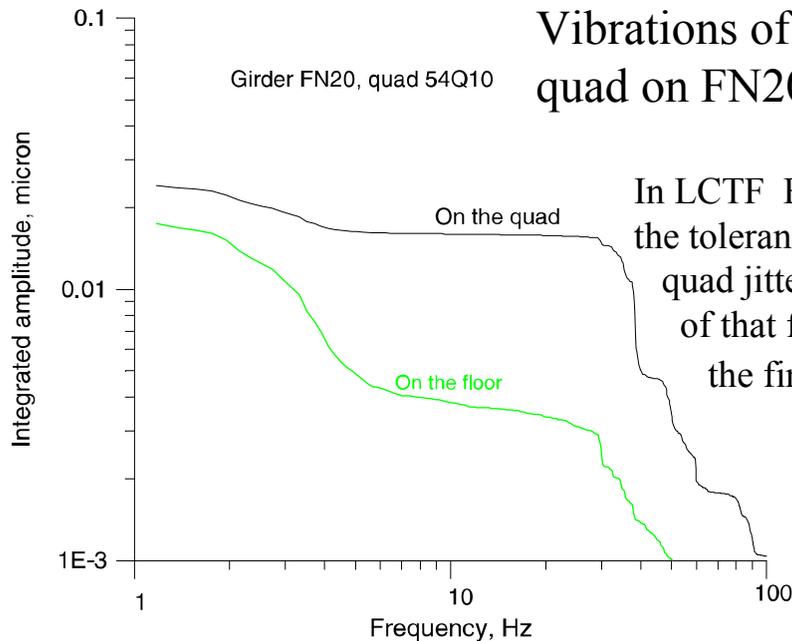
P.Emma

P.Raimondi, A.Seryi



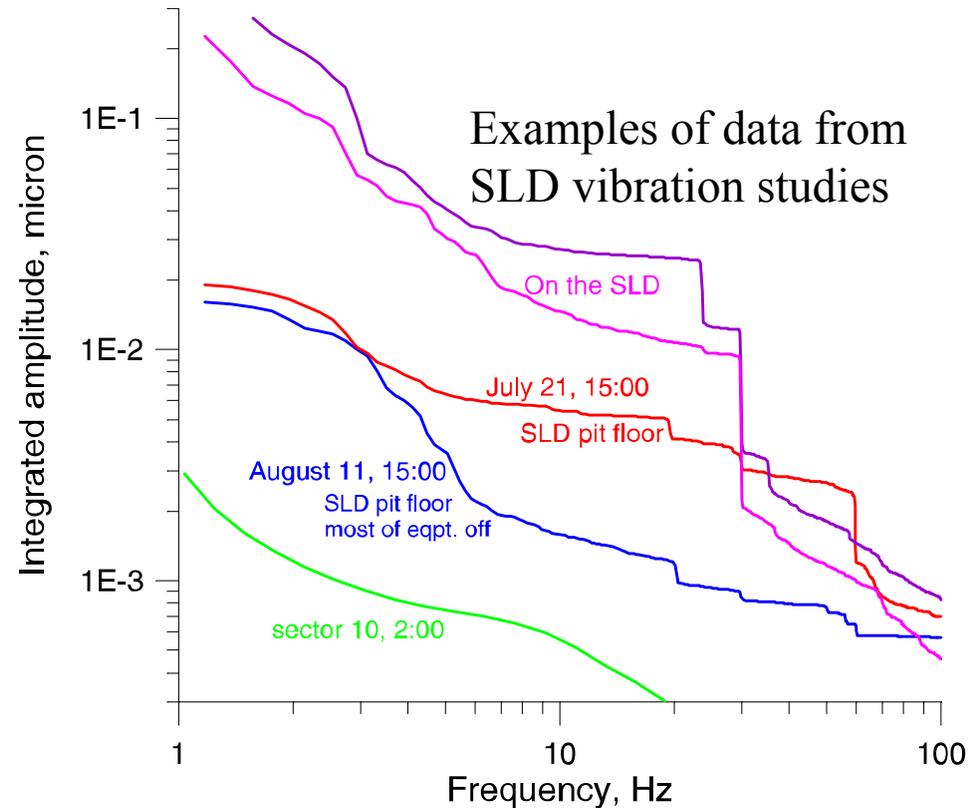
# LCTF vibration issues

- Quad stability in the FF tunnels is OK or almost OK for LCTF
- Can deliberately make situation worse and learn to correct



# LCTF vibration issues

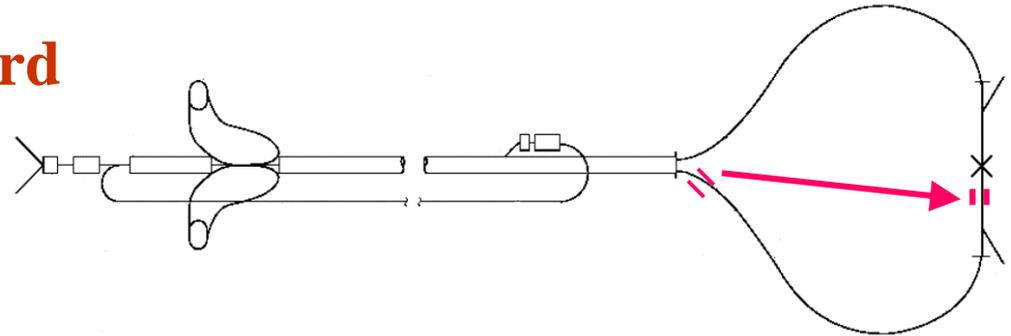
- **Vibration stability in the SLD detector is not sufficient**
- **Need to improve quad center stability by about 10 times**
- **Appropriate counteraction methods should be developed**
- **Learning how to do this is one of the major goals of LCTF**



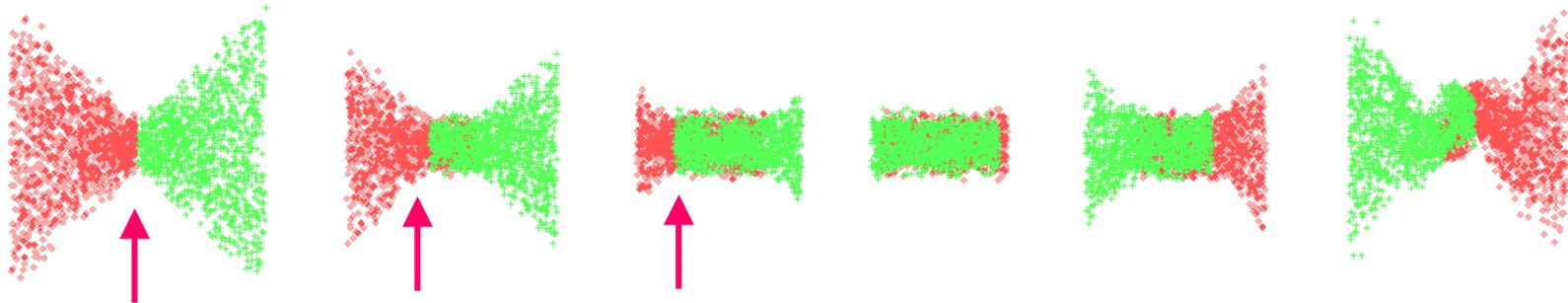
- **Frequencies unreachable for beam-based feedback:  $f > \text{rep.rate}/20$**
- **Linear Collider with 30Hz rep.rate and  $\sigma^* \sim 70\text{nm}$  will give experience applicable to LC with 120Hz and  $\sigma^* \sim 3\text{nm}$**

# What else can be tested @ LCTF?

- Tests of fast feedforward



- Tests of traveling focus (allows to play with  $\beta_y/\sigma_z$ )



Position of focus is moving during collision [Balakin 91]



# More topics to be studied

- **IP jitter from quad vibrations**
- **Linac to IP beam jitter feed forward**
- **Structures on movers (X-band?) for emittance optimization**
- **Global Linac Orbit control and stabilization**
- **IP pair production**
- **New schemes of Background reduction (e.g. Octupoles)**
- **New diagnostic (e.g. OTRs)**
- **and much more (any idea is welcome) ...**



# Conclusion

- **Final Focus System is a crucial point in the linear collider designs**
- **Thanks to years of experience on SLC-FF and FFTB, we have been able to focus what are its main limitations and problems, and design a “Next Generation FFS”.**
- **The present scheme allows for a collider that could be “adiabatically” upgraded in energy through the years up to 5TeV/CM, if the physics community requires it.**
- **More could be gained with moderate money investment. An “LCTF” International Collaboration could better focus all the efforts toward a unique and more optimal Beam Delivery System design.**